Adaptive building design as a platform for enhancing resilience and sustainability in future cities

Taking the case for primary school buildings in Singapore

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Abstract

Rapid urbanization and climate change are two of the major issues challenging many cities today. Recent studies concluded that if cities do not adapt to changes caused by these challenges, the total costs of damage to cities could rise up to USD 1 trillion a year. Even without the effects of climate change, usability of buildings may become obsolete even before they physically deteriorate. In other words, many buildings are not resilient in a changing environment. Designing buildings for adaptive reuse can thus potentially improve cities' resilience by transforming these buildings to function under changing environment.

In case of school buildings, changes in functional criteria or improvement in facilities undergo major renovations or even demolitions after less than 30 years of service. The objective of this study is to identify patterns in the renovations or demolitions of 12 school buildings in Singapore, and propose design guidelines that create alternate designs for these schools that reduce the need or extent of future renovation and demolition. For each alternate design method, the potential net amount of construction and demolition wastes that could be avoided were estimated; by using life cycle assessment, the net decrease in life cycle impacts (global warming potential and acidification potential) and resource requirements (energy and water) were quantified. Savings in life cycle costs and social benefits were also studied and quantified.

It was found that adaptive reuse of school buildings can reduce environmental impacts and costs by 10-20%; case studies by us also indicated that adaptive reuse of buildings enhances the quality of life of communities utilizing these buildings.

Introduction

The project was initiated in collaboration with Ministry of Education of Singapore to improve the quality and future scope of education under the Primary Education Review and Implementation program (PERI), recommended to impart single session model. In a course of time, total 18 new schools will be built and enhancement of 80 existing schools was planned in the future. These constructions and renovations aim to provide flexibility in curriculum.

As a result of this transformation, these renovations resulted in large amounts of construction and demolition (C&D) wastes. The aim of this study is to; firstly, understand patterns in the ways 12 selected old school buildings were renovated. Secondly, environmental impacts and resource consumptions of these patterns of renovations were quantified, before design guidelines were proposed to improve the adaptability of future school building designs. In order to improve the education system, we need to enhance social adaptability and resiliency in urban context rather

than focusing only on the infrastructure. This particular paper will also recommend policies for improving urban sustainability and resilience.

What then is adaptability and why is it important in the context of resilience and sustainability? If one would take a survey on a handful of people, you could find that different people possessing different perspectives and experiences have different responses onto how adaptability is relevant to them. Fortunately, in all the differing uses in adaptability, the theory of sustainability and resilience becomes applicable due to factors like social sustainability; environmental sustainability; economic sustainability and geography, topography & climate influence pertinent adaptability. It is defined by the Oxford Advanced Learner's Dictionary 9th edition* as *the quality of being able to change or be changed in order to deal successfully with new situations*. Importantly, adaptability then is about assuming changes to fit one's environment.

Enabling adaptive building design requires the adoption of a balanced methodology. Therefore, to be able to understand the context of adaptive building design, factors of adaptabilities must be assessed in this paper.

After having considered these adaptations for building, we could then measure the three resources namely cost, time and effort for considerations. As measurements of these resources are quantitative, a point based scale can be used to determine the extent of resources used. Hence, the higher points a type of resource accumulates, the more the use of that resource. Again, this would be described in the portion on methodology.

Methodology

This study is mainly divided into two parts:

1. School Buildings as case studies on the basis of factors of adaptability and resource intensiveness.

12 school buildings were studied; they had undergone renovations and for each of these buildings, the nature of their adaptability was evaluated in terms of four key factors (Fig. 1) – internal adaptability, extension adaptability, use adaptability, and planning adaptability. After assessing the key factors; time, cost and effort were the three resources which helped in collective quantification of the relative adaptive indexes. Internal adaptability refers to the adaptability of the existing interior layout of the building to adapt to future changes of space (for example, segregation of interior space). Extension adaptability refers to the ability to have physical elements, such as an extra floor, be added to an existing structure to allow the building to adapt to new requirement and perform additional functions. Use adaptability refers to the ability of the modified space to be used for alternate uses without any renovations in the future. Planning adaptability is enhanced if supporting structures of the building can adapt to future uses easily by means of using "transformable materials or structures" (for example, by the use of lightweight materials).

For any renovation or demolition performed on each of these buildings, the amount of resources required – namely, cost, time and effort – were estimated and scored; this is termed "resource score". For example, any work that requires installation of structural elements, including demolition of existing blocks, is rated as "high" in cost, effort and time; each of these are given a score of "5" on a scale of 1-5. Any cosmetic modification, including paint work, is rated as "low" and scored "1". In short, every piece of construction job performed on a certain school building was evaluated according to:

i) Improvement in the various types of adaptability, and
ii) Resource score

The higher the improvement in adaptability and lower the resource score, the more desirable the renovation is (Fig. 2).

The environmental impacts of the renovation projects and alternate designs are calculated using life cycle assessment (LCA). LCA is a methodology for assessing the inputs into, and outputs from the various life cycle stages of a product or service; these flows can then be converted into various environmental impacts.

2. Adaptive Design and Use on the basis of Social value and impact

While the first part of this research described the methodology for adaptation and resources used, the second part leads us to an area of great importance. Adaptation can bring a positive social value, but before we can suggest ways of impacting positive social value through adaptation, we need to understand the interpretation. A positive social value refers to the net positive gain in value to the society. Whereas, a negative social value is the opposite. A society can be regarded in terms of territory, area or country like Singapore. In addition, a large positive social value equates to a high impact social value, likewise, for a large negative social value has a high but negative impact. However, social value

derived from adaptation is thus, often intangible to the gain or losses directly or indirectly to the society. Often, this is difficult to define but not impossible. The next relevant question is then '*How do we then create positive social value from adaptive design?*' In this research, we would like to propose an interesting Adaptive design methods to increase the social value to society.

The concept of Adaptive 'Reuse' Design encompasses a reuse of tangible structures such as buildings, adapt them for reuse so as to create more usable space. This is done by adapting the old building and designing the new with the old spaces. There are many positive intangibles that are derived from this concept. Such as old buildings do not need to be demolished but are adapted into the new design. This can be measured from the resources saved from demolition and the avoidance of more materials used when a new building is being built on top of the old. What is the social value or impacts? Being green is one and we are saving resources by not using more than we need. Moreover, by adopting adaptive reuse design, we are also 'recycling' the building rather than demolition and destroying the heritage.

The heritage of a building is imbedded in the characteristics of its form. Such as the façade of the building clock tower, etc. It expresses the values of people who used that building and how they are related to it. It forms the bond between building and people. By demolishing the building, and heritage, and the negative social value that comes is certainly incalculable. By adopting Adaptive Reuse Design in old buildings, a positive role in the preservation of heritage can be achieved.

How else can social values be enhanced? That's where a more dynamic positioning of buildings can add to society's social value. It is in the form called resilience. Resilience is about adaptability and adaptability requires resilience in design. So how can the social fabric of a society be able to see resilience? Recently, around the world and in the South-East Asia, we witnessed times where mass emergencies take place, for instance, terrorism in the United Kingdom and armed insurgency by terrorists in the Philippines. With the current level of international tensions rising up, Singapore has already recognized the value of having bomb shelters in residential premises, but what if we have community spaces that can turn into safe houses in case of emergency. In (Fig. 3) the map of Singapore, if we can layer out the total schools and walk able distances (800m), a network can be created of safe houses if those buildings are converted in multi utility spaces and can be of greater value in case of emergency.

Creative problem solving techniques with discussion of innovative opportunities for inclusive communities can be very useful for the future. For instance, vacant spaces in specific time frames where commercial and educational spaces are under-utilized can be used at their full efficient potential. In order to promote integrated environment for the community, we need more space for inclusive interactions and cohesive activities.

School buildings can be a great opportunity as we see from a social perspective. As school buildings in Singapore have imparted single sessions, seems an opportunity in the infrastructure of the school buildings which remain empty in the major part of the 24-hour time.

Results and discussion

Analysis revealed that after renovations, most of these buildings improved their extension and use adaptability. However, about 50% of these renovated buildings do not have internal and planning adaptability.

Percentages of high, medium and low resources scores for each of the 12 school buildings were evaluated (Fig. 2). It was found that all but one school (school 10) has a majority of high resource scores. In other words, even after incurring large amounts of resources for renovations, only 50% of these buildings improve their internal and planning adaptability. Although school 10 performs the best based on the resource scores, its use adaptability is low.

Notwithstanding this weakness, the original design of school 10 offers a few guidelines for improving future design of school buildings, so that resource consumptions during renovation can be reduced and overall adaptability can be enhanced; they are:

i) Allocate additional buffer spaces, such as recreational spaces, around existing buildings that can be used for extension in the future. This implies that such recreational spaces must be reconfigurable to synchronize with future extension of built up space.

ii) Ensure connections among different parts of the building. These connections should be expanded and even improved after the renovation.
iii) Utilize interior partitions (especially drywalls) or prefabricated demountable panels to enable internal space to be modified according to changing needs.
iv) Ensure a degree of redundancy in the mechanical system, including additional air inlets and outlets.

Life Cycle Assessment calculation results indicate that, on average, the renovations in the 12 buildings incurred 380 metric tons of building materials per building, most of which was reinforced concrete. This resulted in an additional 53.8 metric tons of CO2 equivalent, 4.42 metric tons of SO2-eq, 584.3 GJ of energy and 34.2 metric tons of water.

If all buildings were designed and constructed using the abovementioned four-point guideline, there is a possibility of the average environmental impact to be reduced by 10%.

Conclusions

Detailed evaluations of 12 school buildings in Singapore revealed opportunities for improving the design of future schools, so that adaptive reuse is possible and resource consumption during the renovations of these buildings can be reduced. The general design guidelines based on the study of school 10 can be applied to future school buildings, and there is a potential to reduce the environmental impacts and resource consumptions by 10%.

These results show that it is important for future policies to encourage the implementation of the four-point guideline in school designs, by incorporating this guideline in future version of the Green Mark Scheme, which is the local green building standard and assessment system.

Also, spaces which are designed in a multifunctional could reciprocate in hour of need. Current international crisis, already Singapore has planned bomb shelters as a method of mitigating residential buildings in emergency. Schools buildings are not in use after school hours, what if the design helps to contribute and define spaces for better community uses in turn making the buildings adaptive and resilient for different situations and times.

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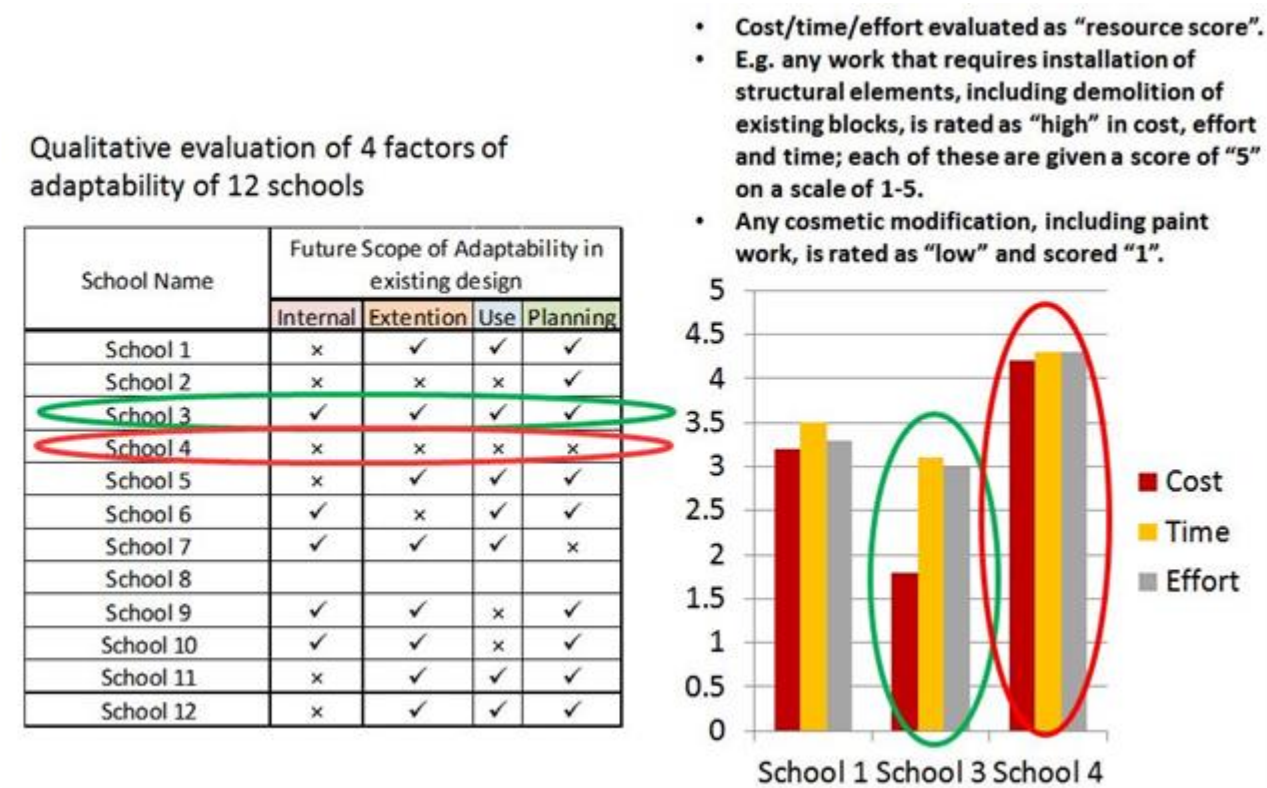
Qualitative evaluation of 4 factors of adaptability of 12 schools

School Name	Future Scope of Adaptability in existing design			
	Internal	Extention	Use	Planning
School 1	×	✓	✓	✓
School 2	×	×	×	✓
School 3	✓	✓	✓	✓
School 4	×	×	×	×
School 5	×	✓	✓	✓
School 6	✓	×	✓	✓
School 7	✓	✓	✓	×
School 8				
School 9	✓	✓	×	✓
School 10	✓	✓	×	✓
School 11	×	✓	✓	✓
School 12	×	✓	✓	✓

Fig. 1: 12 School buildings and the nature of their adaptability; assessing the nature with 3 resource scores

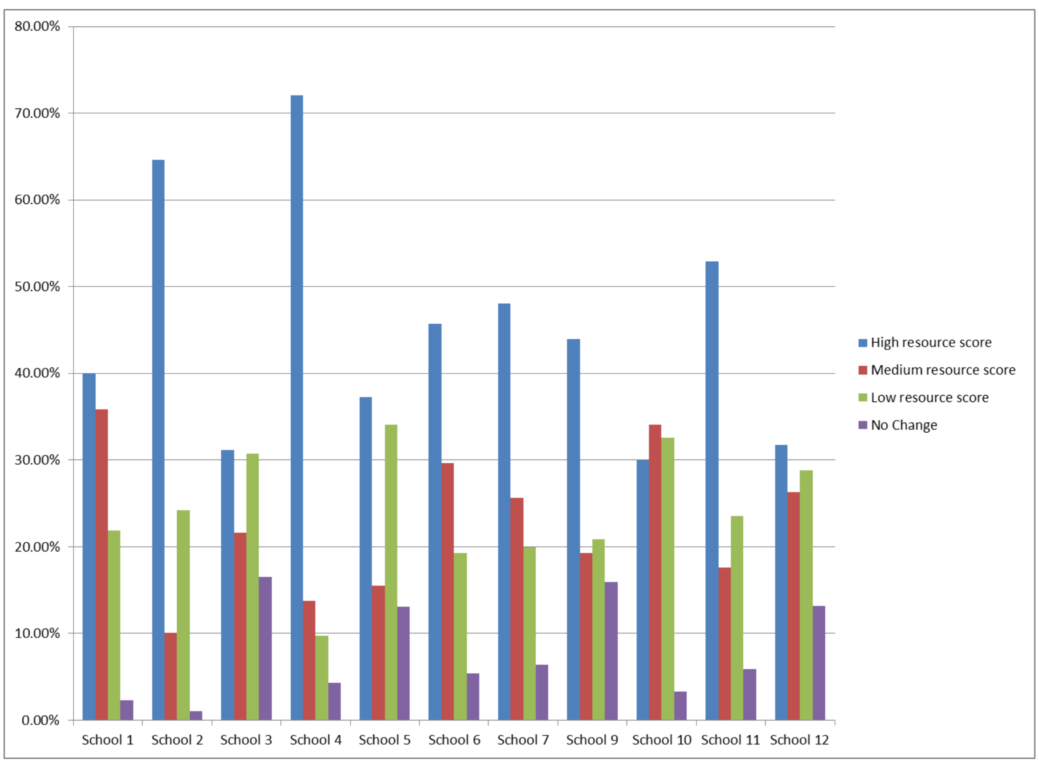

Fig. 2: Percentages of high, medium and low resource scores for the renovation works performed for the 12 school buildings.

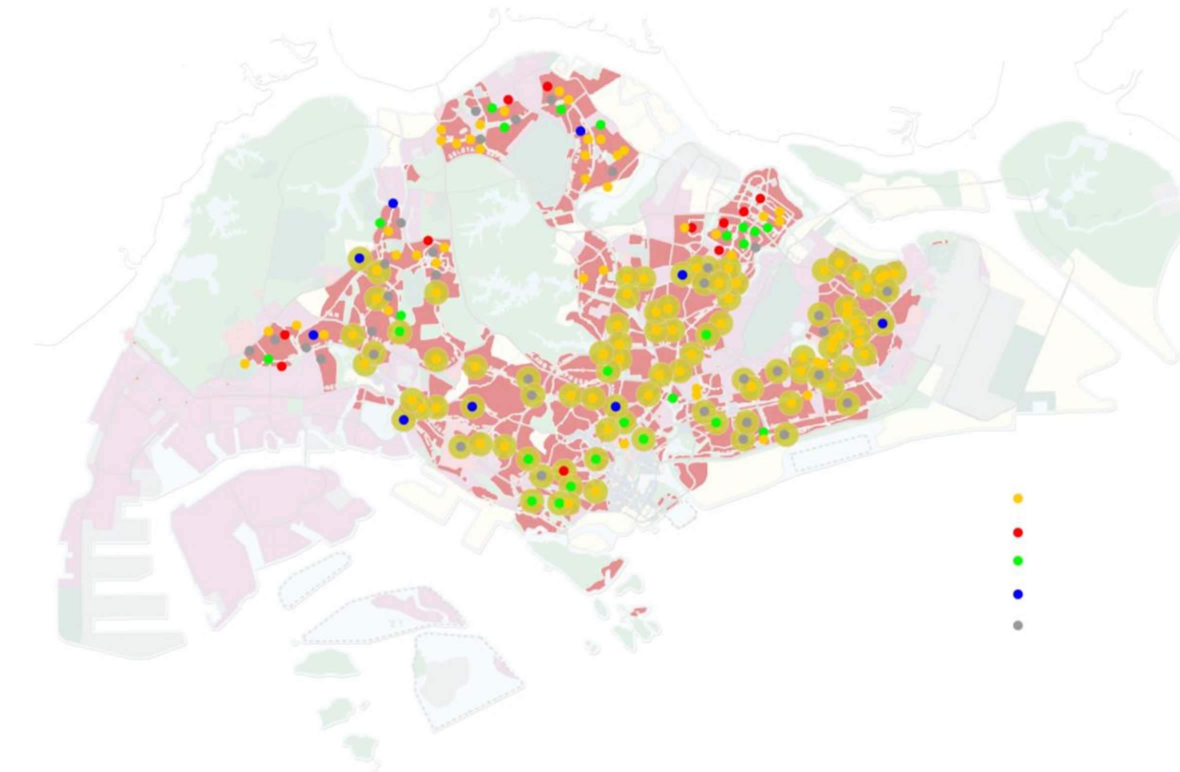

Fig. 3: Map of Singapore showing total schools buildings in context and walk able distance